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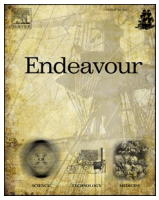

Hoops, loops and eyewitness reliability: a history of biologically impossible aquatic monsters

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ABSTRACT

Here we outline the history of serpentiform aquatic monster reports and images that contain a zoological impossibility: the presence of loops or arches of the body above the water in a vertically flexing animal body. Images of such serpentiform animals have been common ever since the sixteenth century yet the actual proportion of such eyewitness reports, especially at Loch Ness, has until recently been extremely low, far lower than the proportion of hooped imagery in art portraying the Loch Ness Monster. As the biological impossibility of such arched animals is not widely known, yet the images of such monsters both historically and contemporaneously are extremely common, this allows a test of contemporary eyewitness testimony. Few reports mention vertical arches in freshwater or marine contexts. This low proportion suggests cultural background has *not* influenced the content of aquatic monster reports, in contrast to previous work in the field. This insight supports the contention that the majority of eyewitness reports are actually based on some underlying physical reality, even if not representing an actual encounter with an unknown species.

Introduction

The long history of belief in, and reports of, sea monsters has received renewed scrutiny in recent years with historical overviews and analyses by Lyons (2010), Loxton and Prothero (2013), Paxton and Naish (2019) and to a lesser extent Paxton (2009). An emergent consensus is that these reports are affected by the cultural milieu in which they occur. Imagery, even nominally scientific imagery, may not reflect biological reality. For example, images of the famous Loch Ness Monster and sea serpents frequently portray a serpentiform animal with vertical hoops trailing behind the head and neck (Fig. 1, Fig. 2) where there is a clear distance between the body and the surface of the water. Such animals are biologically implausible, as will be discussed below; thus, the fact that such features appear in historical reports – whilst interesting in itself as a cultural phenomenon – provides a method to test the reliability of these reports. If commonplace imagery portrays multi-arched sea serpents, and witnesses are influenced by this imagery, then "archiness" might be presumed to be commonly represented in subsequent eyewitness reports of sea serpents. Integrating historical background into a statistical analysis therefore offers a more complete picture.

The purpose of this paper is threefold:

1. To explore the history of portrayals of arched/looped sea serpents and freshwater monsters.
2. To consider how much the iconography of the multi-arched serpent has influenced eyewitness reports of aquatic monsters (especially from Loch Ness), as a test of the accuracy of reports.
3. To investigate statistically any trends in proportion of reports with hooped/looped aquatic monsters over time in a similar way to previous historical investigations of trends in eyewitness testimony (e.g. Paxton & Naish, 2019).

Swimming analysis

In the following discussions we use "arches" to mean vertical flexations so extreme that a clear space is visible between the water and the body of the animal. "Loops" will refer to curvature such that one or more U-shapes or whole oval shapes are seen in the body, where no clearly-delineated water surface is shown in the image. Hence, according to this terminology, terrestrial snakes could only have loops but not arches. We use "coils" for more extreme curvature such that one curve is within

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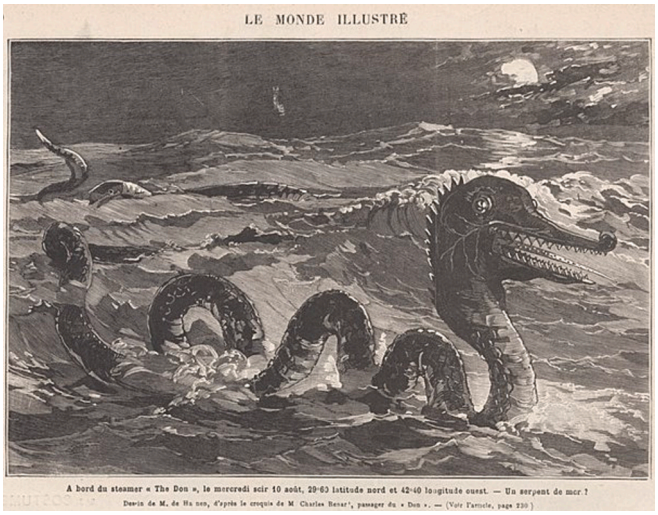

Fig. 1. The (hoaxed) sea serpent reported in the *Monde Illustré*, October 8, 1881, pg. 240. Reproduced from author Paxton's own collection.

Fig. 2. A pre-1971 (exact date unknown) postcard from Loch Ness showing vertical arches. From author Paxton's own collection. Dennis Productions.

another and "undulations" for curves not as extreme as an "arch" or "loop." Note that this is our terminology, not that of witnesses who historically used the above terms and "hoops" interchangeably to mean a variety of degrees of curvedness. When the witnesses reported "humps" these could be the tops of curves otherwise underwater. These eyewitness terms, of course, are considered from English-language sources and subtleties of meaning in other languages may well be lost in translation.

To the best of our knowledge no known extant vertebrate animal has ever been observed with vertical flexations so extreme as to show vertical arches above the surface of the water or land on which they travel. The current consensus is that all extant reptiles flex in the lateral plane, as do fishes. Some eels swim on their sides (e.g. *Anguilla anguilla*[1]; *Conger conger,* Burton, 1961) so any loops may *appear* vertical, but again their flexations do not emerge above the water's surface such that arches can be seen. Cetaceans do move vertically, yet even *Berardius*, arguably the most serpentiform of the extant toothed whales, does not flex so much that arches would be visible.[2] Flexing the body completely out of the water would be inefficient for an animal, as the body would not be pushing against a medium to provide forward thrust (Biewener & Patek, 2018). This insight was realized with regard to sea serpent reports as long ago as the late nineteenth century (Lee, 1883, p. 716) although not all sea serpent scholars *did* recognize this at that time (e.g. Oudemans, 1892, p. 521).

Arches might be seen when a large constricting snake is tackling a prey animal in the water, and arches of this form have been claimed in some sea serpent reports (e.g. see Paxton, 2021 for a discussion). However, no actual snake has been observed to swim with vertical undulations that loop out of the water, as depicted in Figs. 1 and 2, when swimming normally.

Historical background

Sea serpents (i.e. giant marine animals resembling snakes rather than actual aquatic ophidians) have been described since antiquity, as seen in Pliny's *Natural History* (for a full history see Heuvelmans, 1968), and firsthand eyewitness testimony of sea monsters become available from the eighteenth century onwards (e.g. Egede & Egede, 1971; Egede, (1741)). However, the portrayal of vertically undulating serpents seems to date further back. Vertical undulations obviously cannot be distinguished in serpentine images in "plane view," that is, projected onto a horizontal plane. Unequivocal snake images, as opposed to zig-zags, are only known from the Upper Paleolithic (Maringer, 1977). Some of these earliest profile views of presumably terrestrial snakes show only very slight undulations (e.g. the snake on a late Paleolithic "baton" from Montgaudier in southern France, Petersen, 2021). The first in profile, vertical, strongly undulating images of snakes appear much later in the Bronze Age (e.g. at Tanum, Sweden, Maringer, 1977). Similar imagery is even found in the Americas with recent discoveries of pre-Columbian rock art seemingly of large snakes from the Orinoco (Riris et al., 2024). These images were presumably influenced by encounters with anacondas, but the relationship of the serpent to the water is not provided.

Early Chinese dragons, which were often associated with water, can appear in vertical perspective in coiled form – vertical, at least, relative to the head of the animal – but their position in water is not shown (e.g. Bronze Age Shang dynasty art, cited in Wilson, 1990). Overt loops in images of terrestrial snakes in a profile view are known from later periods (e.g. a mural in the House of the Centenary in Pompeii, see Panetta & Deluca, 2005, p. 111). It is clear that this is a stylistic device rather than an actual visualization of snake behavior.

Undisputed aquatic monsters that are not snakes, with vertical undulations and loops, are known from Greco-Roman art. These include tritons (e.g. on a sixth-century B.C.E. hydria, Anonymous, undated); hippocampi and ichthyocentaurs (e.g. on a second-century C.E. mosaic from the Thermae of Ostia, pictured in Andreae, 1973, Figs. 468, 469); serpentine canine-headed monsters (e.g. in Mayor, 1989, Fig. 3); and other strange creatures (e.g. the hybrid creature seen on the sixth-century B.C.E. Caeretan hydria pictured in Papadopoulos & Ruscillo, 2002, p. 219). Even when the water's surface is shown, whether they are below, on, or above the surface can be ambiguous (e.g. Fig. 3). However,

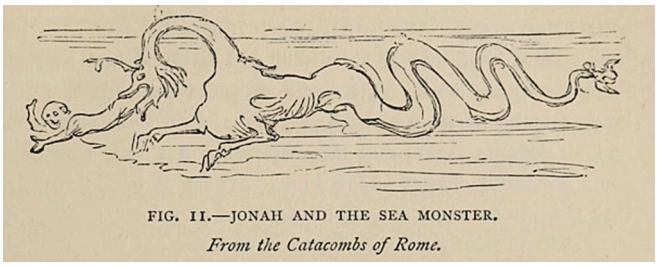

Fig. 3. Drawing of a painting of Jonah vomited from the sea monster from the St. Calixtus catacomb, Rome. From Henry Lee, *Sea Monsters Unmasked* (London: William Clowes and Sons, 1883), p. 55.

[1] Pers. obs. CGMP.
[2] Pers. obs. Leigh Hickmott.

other images in Roman art show unambiguously arched sea monsters at the surface of the water (Fig. 4).

Whilst sea monsters are known in medieval European art, even small aquatic serpents are rare and they are barely mentioned in prose except for medieval encyclopaedias (e.g. Cantimpratensis, 1244). Non-monstrous eels are mentioned and pictured but they do not have arches.

The first images of unequivocal giant sea serpents (as opposed to sea serpent images where the scale is ambiguous (e.g. see the medieval maps in van Duzer, 2013) are found in the sixteenth century in the works of Olaus Magnus from 1539 and 1555 (Figs. 5 and 6, top). Here the sea serpent is shown attacking a boat and the whole body is visible. This Norwegian sea serpent is variously stated by Magnus to be 300 (1539) or at least 200 (1555) feet long and coiled into a ball, but arches above the surface of the water are not explicitly mentioned. However, in another section of the *Carta Marina*, Magnus pictures a worm off Norway which is portrayed as swimming vertically in the water (Fig. 5, bottom) with distinct arches. The worm is described in detail as being 40 (Magnus, 1539) or 60 feet (Magnus, 1998) long, yellow in color, "scarcely as thick as child's arm," and moving like a ribbon through the water. This animal is clearly distinct from the sea serpent for Magnus but its exact zoological basis is unclear. The potential candidates are a ctenophore or nemertean which have not been observed to reach great lengths. The image was also figured (Fig. 6, bottom) in another contemporary source, in slightly different form from the *Carta Marina.*

A variant of the Magnus arched worm image is used by Gessner (1558) but the worm is now clearly depicted as a serpent (Fig. 7). Further Gessner (1558; 1560) also has a derived figure (Fig. 8) of Magnus's sea serpent and says it illustrates his point that "Spiras supra mare tantas aliquando erigere, ut navis per unam transire posset," or roughly "Sometimes the coils were raised so high above the sea that a ship could pass through one." The word "Spiras" here is typically translated into English as "coils" but clearly some sense of an arch is implied from the context. This claim was not found in Magnus's work and appears to be hyperbole of Gessner's own creation.

The next image (Fig. 9) of a sea or perhaps a freshwater arched serpent known to us comes from Johann Ludwig Gottfried's *Newe Welt und Americanishe Historien* published in 1655. It illustrates a moment from Sir Walter Raleigh's 1595 expedition to Guiana (Raleigh, 1596) where a crew member was consumed by a "lagarto," presumably not an alligator from the location, but a black caiman *Melanosuchus niger*). Gottfried's engraver Matthäus Merian probably imagined the animal based on Raleigh's depiction (1596), saying the *lagarto* was a type of "serpent."

Fig. 4. A distinctly looped sea monster from the Sala Rotunda, Vatican Museums, Rome. The mosaics here date from the third century C.E., having been transferred from Otricoli and Sacrofano. .
Source: Eric Vandeville/akg-images. Reproduced with permission

Fig. 5. Sea serpent (top) and sea worm (bottom) from Olaus Magnus, *Carta Marina*, 1539. Public domain.

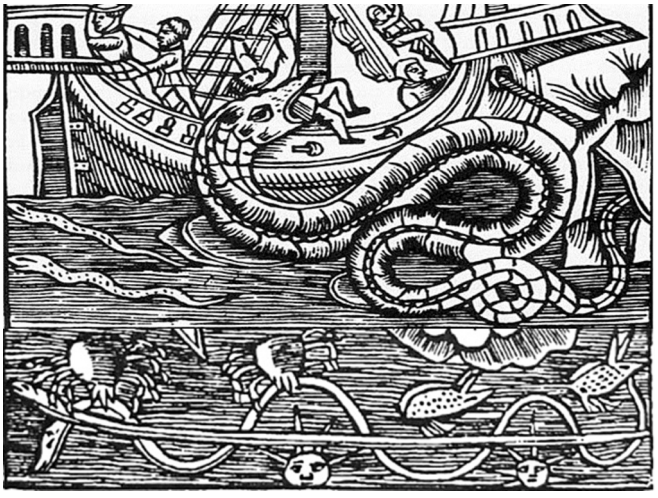

Fig. 6. Sea serpent and sea worm from Olaus Magnus, *Historia de gentibus septentrionalibus* (1555, reproduced in 1998). Public domain.

Starting in the eighteenth century there are specifically-stated *eyewitness* accounts of sea serpents. However, none of the images associated with the accounts collated by Egede, 1741 and Pontoppidan (1752/1753, 1755) have definitive arches. Rather, they have humps or curves that do not definitively leave the water, although later artistic interpretations may invoke arches (see below). Pontoppidan does mention a sea serpent seen off Norway in 1747 that is described in translation as having "folds or coils," a translation of the Dano-Norwegian "bugtar" (modern Norwegian, "bukter," curves or bends).

Fig. 7. The arched serpent from Gessner's *Historia Animalium* (1558), clearly derived from Magnus's 1539 *Vermis*. Public domain, image sourced from the Biodiversity Heritage Library. Contributed by Smithsonian Libraries and Archives.

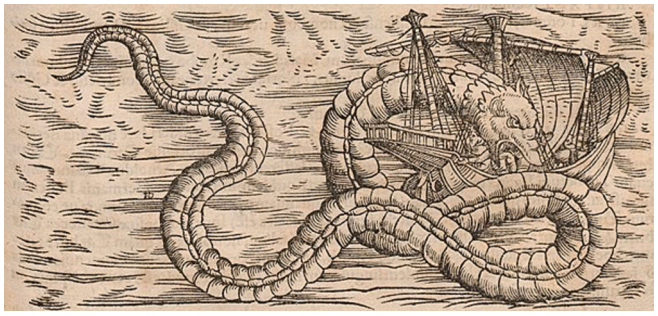

Fig. 8. The illustration associated with Gessner's claim in the *Historia Animalium* (1558) that coils of a sea serpent could be so high as to allow a ship to pass through them. Public domain, image sourced from the Biodiversity Heritage Library. Contributed by Smithsonian Libraries and Archives.

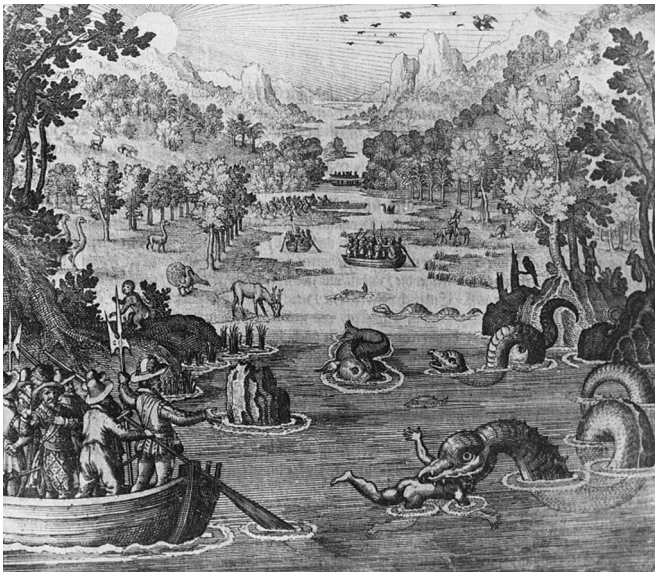

Fig. 9. The loss of a crew member of Raleigh's expedition to Guinea (South America) as illustrated in *Newe Welt und Americanishe Historien* by Johann Ludwig Gottfried (1655, p. 379). Engraving by Matthäus Merian. Public domain, image sourced from Archive.org. Contributed by John Carter Brown Library.

"Coils" is a term that occurs in many subsequent English-language reports but may not necessarily mean arches seen above the water. Again, the original intent of a historic writer's terminology can be difficult to surmise.

Thereafter, there are no reliably arched sea serpent reports known to us, until the first quarter of the nineteenth century. The next sea serpent illustration with definitive arches is that of the New England sea serpent reported multiple times from 1817 to 1821 (Fig. 10), which otherwise was pictured as having horizontal flexations. We do not know from what precursors Fig. 10 was drawn, as vertical arches are not mentioned in the

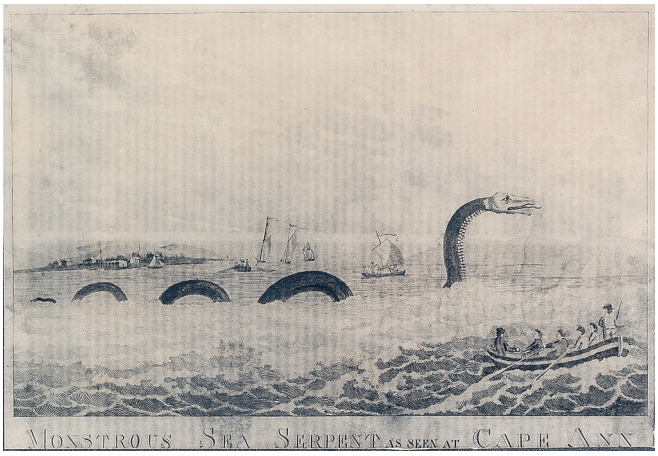

Fig. 10. An early nineteenth-century print of the New England sea serpent, from a now lost engraving, in the collection of the Nahant Historical Society. The exact date is unknown but it is presumably from sometime between 1817 and 1821. Photograph courtesy of the Nahant Historical Society.

textual sea serpent reports from New England from 1817 to 1821, except indirectly for three accounts from 1817. One of these accounts comes from William H. Foster (Anonymous., 1817) that describes the monster as having "rings," but their orientation is not mentioned. In the second account, Matthew Gaffney stated of the sea serpent he saw that "his motion was vertical, like a caterpillar" (Anonymous., 1817, p.16). The third account has been assumed to be by Col. Thomas Perkins in some secondary sources (e.g. Gosse, 1860, pp. 284–285 and O'Neill, 2003); however, it appears to have been only transmitted by Perkins but was actually written by one Capt. W. Compton Bolton. This account described a sea serpent with the "vertical movement of a caterpillar" (Anonymous, 1848a).The next explicit report with reference to hoops, loops or arches we have found was written in 1827 in Norway (Anonymous., 1827). Unfortunately, we have no access to the original Norwegian text. Thereafter, despite arched sea serpents having been reported at fairly low frequencies in published texts, they have often been illustrated, as the next section will discuss further.

It is also worth mentioning that sea serpent images drawn from the fossil record may have served as sources in later accounts. The first and only arched "sea serpent" to our knowledge in a palaeontological context, prior to the more recent discoveries of giant snakes like *Gigantophis* (Andrews, 1901) and *Titanoboa* (Head et al., 2009), comes

Fig. 11. Plesiosaurs, ichthyosaurs and an arched serpentine animal from Thomas Hawkins's 1840 *Book of Great Sea Dragons*. The artist was John Martin. Public domain, image sourced from the Biodiversity Heritage Library. Contributed by Harvard University.

from 1840 in Thomas Hawkins's *Book of Great Sea-Dragons*. In a plate (Fig. 11) illustrated by famous contemporary British artist John Martin (Myrone, 2011), the background shows a possible looped marine reptile of uncertain affinities. This image is interesting in that at the time no overtly serpentiform Mesozoic marine reptile was known. Plesiosaurs, which have been proposed as a candidate for reported sea serpents (see Paxton & Naish, 2019 for a review) were recognized as serpent-like, at least their necks (Buckland, 1836, p. 202; Cuvier, 1836, p. 455). However, they were clearly not snakes, just animals with long, curving necks. So presumably Martin was influenced by sea serpent images he had seen elsewhere.

Whilst overt sea serpent images were apparently rare in palaeontological texts, one animal that could be portrayed as serpentiform was the primitive Eocene whale *Basilosaurus*, previously *Zeuglodon*. *Basilosaurus* was typically pictured with undulations (e.g. see Charles Knight's famous paintings at the Field Museum in Chicago also in Milner & Knight, 2012). Popular accounts (e.g. Anonymous, 1918) sometimes exaggerated basilosaurs to an elongated coiled form that swum so strongly it could propel itself from the water! On at least one occasion slightly arched, seemingly buoyant basilosaurs even made their way into a palaeontological text drawn by Andrew Janson (Olson, 1959, p. 21).

References to arches can insinuate themselves into historical accounts of sea serpents even when they were not directly described in older or original sources. For example, in the *Amphibious Carnivora* (Hamilton, 1839) the sea serpent described by Hans Egede in 1741 is re-illustrated in a distinctly arched manner (Fig. 12) although this was not in the original description or drawing. Another example is that of the Rev. John Macrae and others, who gave several accounts of the Macrae family's encounters with a sea serpent in August 1872 without mention of loops (e.g. a newspaper account: Macrae, 1872). Yet in a follow-up account written a month later, on September 23, 1872, but not published until thirteen years later in a newspaper, Macrae refers to the serpent "bend[ing] their bones in a series of loops…" (1885).

By 1848, a year marked by some prominent sea serpent accounts in the press, the arched sea serpent concept seems so well established that it was even used in cartoons in the bestselling humor magazine *Punch* (Fig. 13; Anonymous, 1848b). The vertically looped monster motif also made its way into folkloric accounts of aquatic monsters: for example, the frontispiece illustration in *Popular Tales of the West Highlands*, by J. Campbell (Fig. 14) published in Campbell (1890).

Reporting arches may be indicative of the overall falsehood of the eyewitness account. On August 10th, 1896, one (possibly self-styled) "Professor" R. H. Mohr described a sea-serpent whilst sailing with his son off the coast of Nahant, Massachusetts:

"… The ocean looked like glass in its smoothness, and just enough air was stirring to move us along at a fair rate of speed… suddenly we heard a loud sound like that of escaping steam from the exhaust on a boiler, and another like the side wheels on a paddle steamer. We looked for a boat near us and saw none Then up came a head resembling that of a seal, except that it was somewhat larger and had a horn about a foot in length projecting out of its forehead… We had not gone far when the head appeared again, and this time it was followed by an immense loop, and another and another, and a fourth which did not come wholly out of the water, as did the others, and we then discovered that the steam-like sound which first attracted our attention came from this creature.

Each loop was crowned with a thick fleshy fin, and the thing moved not by jumps and starts, but with a measured wheel-like motion, which produced the sound like the side wheels of a steamer boat, while from the mouth came the other sound… My son took the oars, and I hauled the sails close and took the tiller and headed for the Swampscott weirs, the nearest point. The creature circled our boat and disappeared. Quite relieved, we continued our course, and had gone about a mile and a half when we again heard the steaming sound, and to our surprise saw the thing in advance of us ploughing along through the water… so near were we to it that we could almost touch it with an oar.

It circled us again, and then spread itself about thirty feet on the

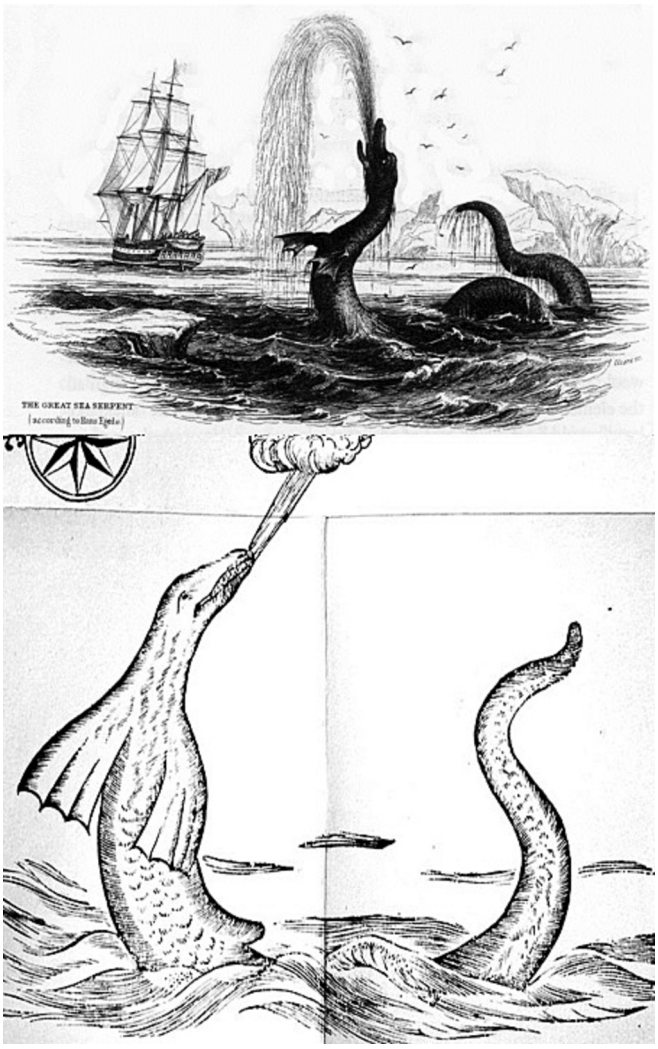

Fig. 12. Upper: Retrospective application of the arched form to the Egede sea serpent from Robert Hamilton's 1839 *Amphibious Carnivora* from the Naturalists Library series. The artist was James Hope Stewart. Lower: the original image of the sea serpent from Hans Egede's *Det gamle grønlands nye perlustration* from 1741. Reproduced from author Paxton's own collection.

Fig. 13. Cartoon in *Punch* (Anonymous, 1848b) commenting on the sea serpents of 1848 and the 1848 French Revolution. Public domain. Reproduced from author Paxton's own collection.

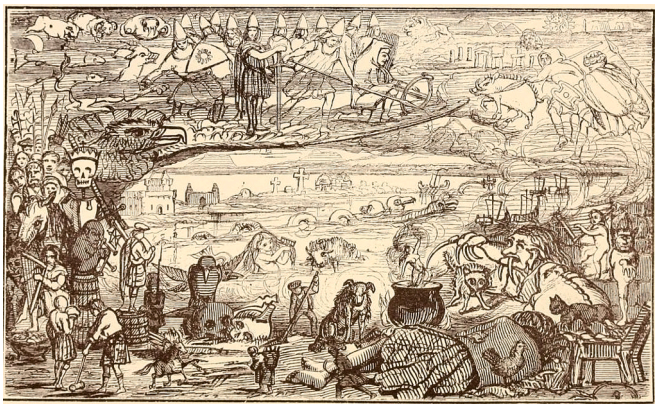

Fig. 14. The frontispiece from J. Campbell's 1862 *Popular Tales of the West Highlands* (Edinburgh: Edmonston and Douglas) with an arched serpent in the background. Reproduction courtesy of the University of St. Andrews.

surface of the water across our bow. This time there was no mistaking what it was…" (Mohr in O'Neill, 2003, p. 256).

There are some incongruities about this report which make it dubious, independent of the reported "loops": a wind moving a boat at a "fair rate of speed" does not leave the sea looking "like glass," for example. The witnesses heard strange loud sounds which subsequently denoted progress of an immense creature on the surface but see nothing, even when looking around for a boat. Mohr hauled "the sails close," i.e. boom towards the center of the boat, and yet his son is rowing the boat at the same time. With the foot of the sail and probably a boom about his head, the poor boy would have been coping with the boat heeled over to leeward as a "close hauled" boat would be. The professor saw the animal at an oar's length but only got the best view when it was further away: "this time there could be no mistaking what it was." Not surprisingly, our research revealed that R. H. Mohr was something of a showman. He was a ventriloquist and illusionist, and he either was or had previously been manager of the Lyceum Theatre in Boston at the time of the report (Anonymous, 1894; Anonymous, 1896). So overall, we have a not very credible witness using loop imagery in a contradictory report.

Statistical analysis

While the creatures described up to this point were allegedly observed at sea, bodies of fresh water have not been immune from reports of looped serpents either. At Loch Ness in Scotland most especially, the popular iconography of the Loch Ness Monster is of an often green, often reptilian monster with arches. This is readily seen in "Nessie" trinkets and cards found in souvenir shops (e.g. Figs. 2 & 15). To provide a crude but nevertheless measured investigation of depictions of this famous freshwater beast, we conducted two analyses of Loch Ness Monster postcards. A collection of the first 60 postcard images that came up after a Google search for "Loch Ness Monster postcard" on September 23, 2019 revealed 15 (25 %, 99 % confidence interval: 14 – 41 %) had arches in the vertical plain above the surface. In the 34 postcards that show Nessie in water in the booklet *A Postcard from Nessie* (Dee, 2020), 11 (32 %, 99 % CI: 16 – 54 %) have visible above-surface arches. It is clear that the arched monster imagery represents a big part of the popular perception of the Loch Ness Monster. Postcards of other, non-Nessie "sea serpents," are also common. A sample of 26 "sea serpent" postcards that portrayed a marine animal from a search on eBay.com on December 5, 2024, revealed 12 (46 %, 99 % CI: 24 – 69 %) that had clear arches above the water.

We did a further statistical survey of available reports. The data consists of historical reports of sea monsters and Loch Ness monster reports collected by the authors. Details of these data sets and previous work can be found in Paxton (2009), Paxton and Shine (2016a), Paxton and Naish (2019) and Paxton et al. (2025). These historical reports were collected independently before the consideration of these analyses described above and so can be considered unbiased with regard to the hypothesis under consideration. Only firsthand accounts were considered. The single report with the most relevant information was extracted from each encounter to ensure statistical independence. As cultural influences on reports were of interest here, only the year of the report, rather than year of the encounter, was considered in the following analyses. Of interest were how any arches or loops or similar terms were used to describe the torsos of the putative animals seen. For all the trend analyses below only reports that contained information on body form were considered to control for the total information content in the report. All analyses were performed in R (R Core Team 2013).

Fig. 15. Arched Loch Ness Monster merchandise in the Loch Ness Centre shop, June 2023. Photograph by Adrian J. Shine.

Of 588 independent first hand reports from Loch Ness only 1.5 % (99 % confidence interval 0.7 – 3.5 %) reported "hoops," "loops" or "arches." There was no evidence ($\alpha = 0.01$) for any trend in loopiness over time (1933–2016: Binomial Generalized Linear (GLM): $P = 0.883$). The terms "coil" or "undulation" are very occasionally used by witnesses as well, which might also imply hoops. Together "hoops," "loops," "coils" and "undulations" represent 2.4 % (99 % confidence interval 1.2 – 4.7 %) of all available firsthand independent reports from Loch Ness. There was no evidence ($\alpha = 0.01$) for any trend in this data in terms of time (1933–2016: Binomial GLM: $P = 0.763$).

Similarly looped/arched reports are a small proportion (4.0 %, 99 % confidence interval 2.2 – 7.2 %) of the 446 independent firsthand reports of sea monsters. Here though there was evidence in time for a positive trend with more arched reports (1750–2016, Binomial GLM: $P = 0.005$, Fig. 16). If coils and undulations are also considered as well as arches and loops in marine accounts, then the total proportion is 7.4 % (99 % CI 4.8 – 11.3 %). There was weak evidence of a positive trend in these reports in time (1750–2016, Binomial GLM: $P = 0.021$). Thus the statistical analyses indicate that arches/hoops/loops are a meager proportion of the total reports and there is some evidence for an increased proportion of arched etc. reports over time.

Discussion: eyewitness accounts and biological possibilities

Images of aquatic serpents with vertical arches above the surface of the water are commonplace, but such behavior is biologically

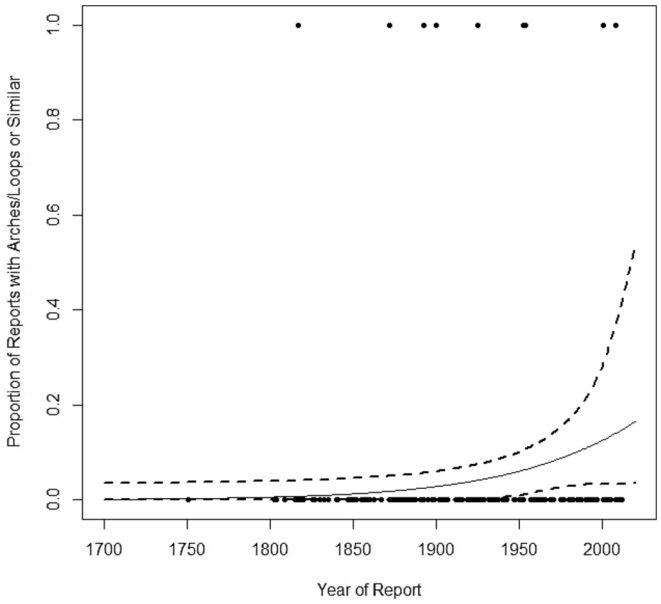

Fig. 16. Proportion of sea monster reports that mention arches, loops, rings or similar terms, through time. Solid line point estimate, dashed lines (0.005 and 0.995 confidence limits). Points indicate reports with (Proportion = 1) and without (Proportion = 0) arches/loops/etc.

impossible. This historical survey suggests that vertical arches perhaps arose as a device to show the looped or undulating, but not necessarily *vertical*, nature of some elongated sea animals which then shifted into an artistic motif of vertical flexations. Further work could consider how the proportion of horizontal to vertical imagery has shifted over time.

We obviously cannot know with absolute certainty what any particular witnesses meant by the terms "hoops" and "loops," and it seems possible that "coil" to some witnesses implied vertical flexation above the water too. But given the frequency of terms like "humps" and "bunches" in aquatic monster accounts as well, it seems that, in English, writers and speakers will make a distinction between solid lumps and open arches, although perhaps witnesses might envisage humps as the just-visible tops of vertical arches. Further, "hoops" and "loops" may refer to horizontal undulations rather than just vertical ones, and the meaning in historic documents is often ambiguous to twenty-first-century readers. Presumably, these subtleties carry over to accounts in other languages as well.

Nevertheless, the existence of arched reports allows insights into the monster reporting process. If the witnesses are telling the truth, and are referring to actual arches, then they must have inaccurately interpreted what they had seen. In actuality, they either did not see spaces under body segments or they saw some objects that were not *one* single animal: for example, flocks of birds, tree branches or debris (see examples in Paxton & Shine, 2016b for many such different explanations from Loch Ness), or animals entangled with debris (e.g. France, 2019a,b). If true, the reports of arched water monsters suggests witnesses misinterpreted what they saw, possibly because of weather, viewing angles or other conditions at the time.

The results suggest that a minimum of 1 – 3 % of freshwater aquatic reports (if only considering "arch" and "loop") should be regarded as misinterpreted (that is, the witnesses are reporting something they have not actually seen *at all*) or represent complete falsehoods. This proportion has not changed at Loch Ness over time. The proportion is slightly higher for marine sea serpents, but nowhere near the proportion indicated by postcards. There is, however, a trend over time towards more "archiness" in the marine reports. The reasons for this are unclear and worthy of further investigation.

Obviously, these figures for the proportion of misinterpreted, misperceived or totally false reports represent an absolute minimum estimate, but to our knowledge this does represent the first quantifiable evidence without experimentation into the accuracy of aquatic monster reports. However, we also know the witnesses are not necessarily outright lying, as some of the reports (notably those from San Francisco Bay in the early 2000s, Clark & Clark, 2001) are supported by film, albeit film that suggests the arches seen may well have been flocks of birds.

Recent qualitative cases for cultural influences on cryptozoological reports have been made by Radford and Nickell (2006), Radford (2011), Loxton and Prothero (2013) and Paxton (2015), and in 2019 Paxton & Naish demonstrated that such trends could be detected statistically. Yet here with regard to reported arches, the available imagery appears to have influenced only a small amount of witnesses who then recorded their observations. There is a notable mismatch in the proportion of archiness in aquatic monster imagery in artwork and film and television and what witnesses actually report. This all suggests that when there is an underlying physical reality to what the witnesses are reporting, cultural influences are not always the most important factor. That reality does not, of course, mean that they are seeing an unknown species of animal. The cultural influences on cryptozoological reports are clearly complex.

CRediT authorship contribution statement

C.G.M. Paxton: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **A.J. Shine:** Writing – review & editing, Resources, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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